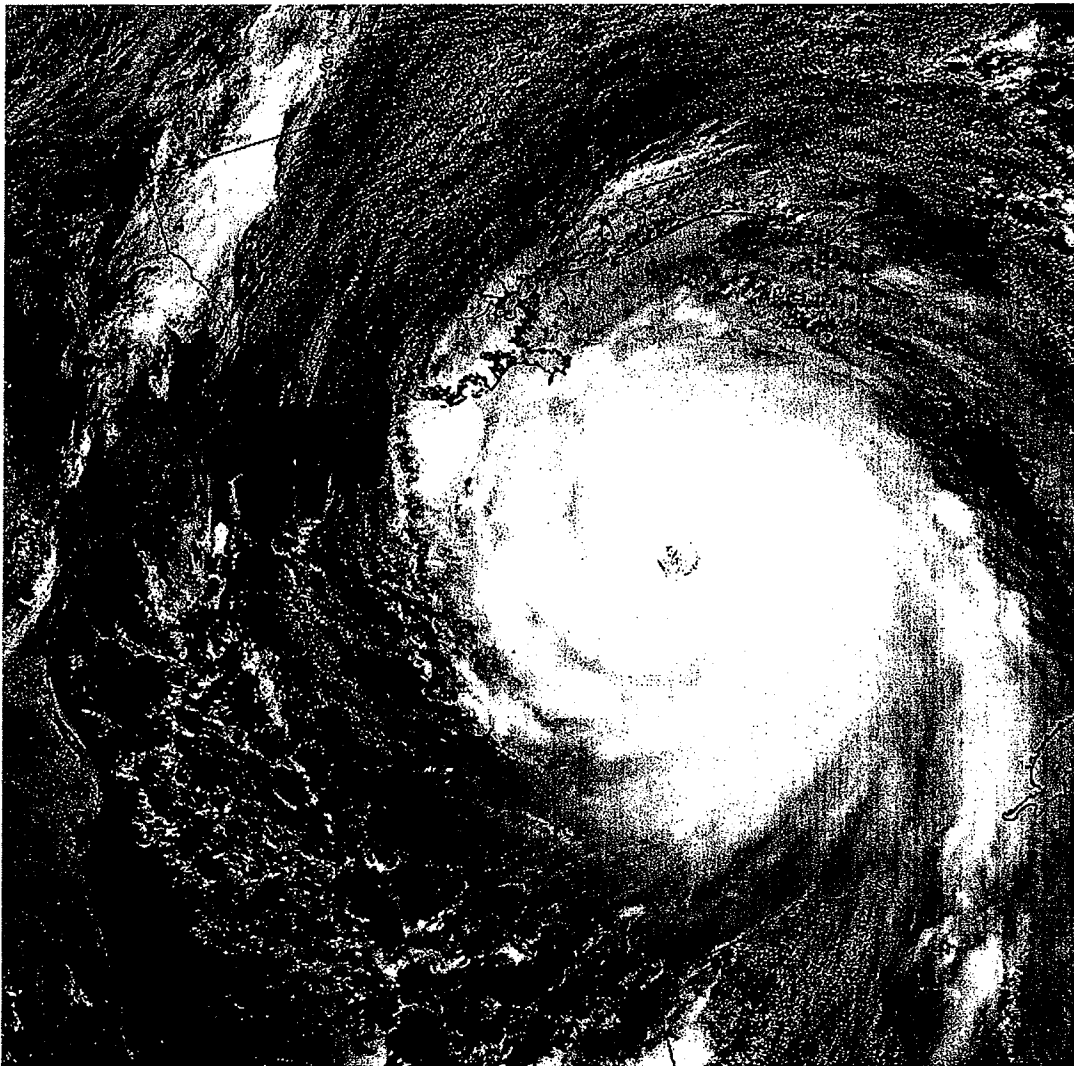


# **EXHIBIT 3**

# **The wind and surge of Hurricane Katrina on 100 Waverly Drive, Bay St. Louis MS**

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Satellite image from on August 28, 2005, at 12:00 PM. Hurricane Katrina was about 200 miles from southeast Louisiana at this time as a Category 5 hurricane.

This report presents information about Katrina's wind and storm surge elements at 100 Waverly Drive in Bay St. Louis, MS. Section 1 provides background information on the physics of the storm surge. Section 2 describes Katrina's wind field, its storm surge, and the timing of both events. Section 3 summarizes the findings.

## 1. Background on the hurricane storm surge

Accompanying a landfalling hurricane is the *storm surge*, defined as an abnormal rise of the sea along the shore generated by an intense storm such as a hurricane. The storm surge is caused primarily by the wind stress pushing water toward the coast. A secondary contribution to surge is made by the reduced barometric pressure within the storm, which causes a dome of water level higher than the surrounding ocean. The slope of the ocean floor as well as land topography also plays a large role. The surge rises gradually, then quickly as the storm makes landfall. Despite some ill-conceived notions, it is not like a tsunami or a wall of water, but instead a steady increase in water levels. Typically the surge peaks after landfall, with a region experiencing tropical storm- and hurricane-force winds several hours before landfall. Observations from several hurricanes, including a special field program by the USGS in Hurricane Rita (2005), confirm that the surge peaks after landfall.

Factors which impact storm surge elevation include:

- *Storm size*: The larger the areal extent of tropical storm-force winds, the higher the water elevation. This is because not only will winds blow inland longer and transport water, but the earth's rotation creates a longshore current that requires a north-south difference in water heights to achieve a balance.
- *Storm central pressure*: Lower interior atmospheric pressure increases the water level. Pressure is essentially the "weight" of the atmosphere. The atmospheric pressure is much lower in the center than at the periphery of the storm. This means the weight of air pushing down on the water column is greater at the edges of the storm than it is at the storm's center. Consequently, a slight bulge, or increase, in the water surface occurs within the storm, and the magnitude of the bulge is greatest at the storm's center and decreases to near zero at the storm's periphery. This water expansion due to lower interior pressure is known as the *inverse barometer effect*. It causes water to expand 3.9 inches for every 10-mb pressure drop. Overall, this is a minor but non-negligible contribution to the storm surge (between 2-3 feet in the inner core of Katrina).
- *Storm intensity*: The maximum wind speed is the most important factor. The more intense the hurricane, the higher the water elevation.
- *Bathymetry*: As the surface currents driven by the wind reach shallow coastlines, bottom friction impedes the seaward return flow near the bottom, causing water to pile up. Shallow areas with a gradual slope will experience greater storm surges than areas with a shelf that drops off rapidly near the coast. This is because water cannot sink and flow outward to the ocean, thereby causing more water to pile up

offshore when the water is shallow. Because of Mississippi's proximity to shallow water that gradually deepens offshore, the state is prone to high storm surges.

- *Topographical forcing:* The wetlands are a coastal land feature that acts to catch water being pushed. As inundation occurs, the land retards the flow of water, causing it to accumulate. Compounding this buildup is the levee system. The Mississippi River levees themselves become a topographic control, acting in the same manner as the delta because the levees extend nearly its entire length. Simulations show water piling up along the Mississippi River levees then moving northward through the eastern Louisiana marshes then onto the Mississippi coast.
- *Speed of motion of the system:* Because a slow moving hurricane has a longer time to transport water onshore, slow systems are associated with higher storm surge values. Slower moving hurricanes can cause a storm surge 50-70% higher than fast moving hurricanes. Fast moving hurricanes cause the surge to "spike" over a few hours with an overall lower surge.
- *Wave setup:* Water levels can increase from onshore waves in windy conditions. Under normal conditions, waves that reach the coast break and water flows back out to the sea under the next incoming wave. In hurricane conditions, the water may not completely retreat before the next wave arrives, a situation called wave setup. This wave setup can be quite large (up to 23% of the wave height) and is most pronounced when deepwater is near the shore, because in shallow water waves break further offshore. Wind-induced surge enables waves to penetrate much further inland before they break. However, in Mississippi and Louisiana where the ocean floor's slope is gentle and shallow, and onshore wave heights are small (see discussion three paragraphs below), wave setup only plays a small role to the peak surge values (0.5 to 2.0 feet).
- *Track angle:* Storms which make landfall perpendicular to the coastline produce larger storm surges than those which hit at an angle. Storms which make landfall at an angle have a smaller surge because some transported water experiences reflection and cross-current transport.
- *Local effects:* The shoreline trajectory can enhance or weaken the surge through trapping mechanisms.

The storm surge is always highest on the side of the eye corresponding to onshore winds, which is usually the right side of the point of landfall. Winds are also fastest in the right front quadrant because storm motion (which averages about 10 mph but varies substantially) is added to the hurricane's winds. Because winds spiral inward, the storm surge is greatest along the eyewall but high water can impact other regions as well.

The total elevated water includes three additional components - the astronomical tide, the steric effect, and ocean waves. The astronomical tide results from gravitational interactions between the earth and the moon and sun, generally producing two high and two low oceanic tides per day in most U.S. locations, but only one high and one low tide per day in Mississippi. Should the storm surge coincide with the high astronomical tide, the additional elevation will be added to the water level. However, tide ranges along the

northern Gulf of Mexico are small, only contributing to one-foot of additional water at high tide, often less. Another contributor is water temperature. Because warm water expands, water levels are naturally highest in the summer, known as the *steric effect*. In the Gulf of Mexico, this contributes about 0.52 feet of water in late summer.

By definition, storm surge does not include waves (other than the contribution due to wave setup). Waves will be superimposed on the storm surge. Miles offshore in deep water, the waves will be large. However, as the depth decreases toward the shore, waves are impacted by the ocean floor and slow down while their period remains constant. As a result, the wavelength decreases and the amplitude increases. Eventually the wave will get too steep and break. New waves will be generated with less height, but as the depth continues to decrease, they will again break and reform as smaller waves. In theory locally generated shallow water wave heights can reach 73% of the water depth, but the distance traveled to reach its potential maximum height (called the fetch) is too short near the shore; because the depth keeps decreasing, wave growth becomes disrupted and the wave will break again and again. In addition, shallow water waves also lose energy due to frictional interaction with the ocean floor. Frictional loss is even greater over flooded, vegetated land.

Wave height can be calculated based on shallow water physics, wind speed, water depth, shoaling factors, fetch distance, and frictional dissipation from vegetated land. Far inland at Waverly, the reduced water depth, limited fetch, vegetation, trees, and buildings, would reduce wave height to 1 foot or less.

## **2. The wind and storm surge of Katrina at 100 Waverly Drive**

### *1. Katrina's windfield*

Katrina was a major hurricane when it made landfall in Bay St. Louis. Because it was also an unusually large hurricane, Mississippi and Louisiana were exposed to hurricane-force winds for many hours, including several hours before landfall. Katrina's hurricane-force winds extended 120 miles from the storm center, and tropical storm-force winds 230 miles outwards. Katrina also maintained a large eye, thereby providing a large areal coverage of its most fierce winds. Satellite, National Weather Service radar, airborne radar (from the Hurricane Research Division), and dropsonde data, provide intriguing insight into the three-dimensional structure of the hurricane. Another band of strong thunderstorms from a second eyewall also impacted the region. The strong winds aloft also created a situation where potent wind gusts could occur in thunderstorms and boundary layer turbulent eddies. National Weather Service radar data indicates many tornadoes, and satellite shows mesovortices on the inner edge of the eyewall capable of extreme wind damage (similar to the damage caused by mesovortices in Hurricane Andrew). The widespread wind damage along the coast is likely due to the longevity of hurricane-force wind exposure, fierce wind gusts, tornadoes, and mesovortices.

The official NOAA sustained wind analysis (known as HWINDS) was used to determine the winds at 100 Waverly Drive. Tropical storm-force winds began around 1:00AM August 29 on Waverly Drive, with hurricane-force winds beginning 6:45AM. Landfall on Waverly Drive occurred at 9:00AM with 110-mph sustained winds. As will be discussed, land inundation began about 9AM at Waverly Drive, and peaked around 11:30AM. Hurricane-force, then tropical storm-force winds continued for another few hours, but of less intensity. In other words, Waverly Drive was subject to tropical storm-force winds from conservatively 1AM to the early afternoon, and hurricane-force winds from 7:00AM to 11:30AM. The early morning winds are conservative. Frictional reduction as wind blows overland from the east was assumed. In addition, there is the possibility (as discussed in the Powerpoint attachments) that the official National Hurricane Center winds are too low. It's feasible the sustained winds were even stronger. It should also be noted that wind measurements taken by wind towers located at the Stennis airport were determined to be too low, since a dropsonde fell in that region showing stronger winds (details are contained in Powerpoint attachments).

Wind gusts 20-100% higher than the sustained winds frequently impacted the residence. The official NOAA peak wind gust at Waverly Drive is 130 to 140 mph, which is also consistent with radar and dropsonde wind data. This general area (Bay St. Louis) received the strongest wind gusts on the Mississippi coast. Two dropsondes were deployed near Bay St. Louis and Gulfport around 6:00AM which recorded winds of 115 mph and 119 mph at an altitude between 500 and 1000 feet, three hours before landfall (and the peak sustained winds). Downbursts associated with severe squall lines can transport these winds to the surface. The first squall line containing a radar reflectivity of

between 45-50 dBZ arrived at 5:45AM, signifying when such winds gusts could be transferred downward. Microwave imagery, which is strongly attenuated by hydrometeors (suspended water and ice particles, as well as precipitation), clearly shows this squall to be a well-formed curved band which is likely an outer eyewall. This outer eyewall reached Waverly Drive about 6:00AM, initiating peak wind gusts reaching 105 mph, with even stronger gusts possible in isolated regions. The inner eyewall reached Waverly Drive around 9:00AM. At landfall, another dropsonde in Bay St. Louis showed winds of 155 mph at 1000 feet. This indicated that wind gusts between 130 and 140 mph were possible in this region at this time. There was obvious roof damage as well as missing sections of roof in some locations which would support such winds as well.

Based on this analysis, pre-landfall USGS tide gauge data, and other National Weather Service observations, a timeline can be established for the wind at 100 Waverly Drive, and is summarized in Table 2.

There is also the possibility of a localized event with extreme winds. These could be mesovortices, downbursts, or tornadoes. Details are provided in the attached Powerpoint slides. However, it should be noted that Doppler radar detected many *mesocyclones* (rotating thunderstorms). Unfortunately, the mesocyclone algorithm is also fraught with uncertainties. The software was developed for mid-latitude, inland severe thunderstorms, not hurricanes. Furthermore, hurricane mesocyclones tend to be small and shallow, resulting in a low probability of detection. Finally, many mesocyclones do not produce tornadoes. Actual observed mesocyclones (not radar-detected) show 10-30% of mesocyclones in the Great Plains produce tornadoes. However, since an equal number are not detected, this implies the false signals and undetected signals cancel each other out, giving a good estimate of the total number of tornadoes.

With these caveats in mind, both the Slidell and Mobile Doppler radar show mesocyclone activity. The number of mesocyclone signals for the Slidell radar are 237, while 204 are detected by the Mobile radar (not shown). When one accounts for the uncertainties involving the ratio of tornadoes to mesocyclones, duplicate mesocyclones, and unseen mesocyclones, one could estimate around 100 tornadoes in Katrina on August 28 and 29.

During the inspection of the apartments, it was noted that debris had penetrated the wall in one building. This is one indication of a possible localized wind event such as a microburst, mesovortex, or tornado.

## *II. Timing of wind and storm surge in Katrina at Waverly Drive*

Observations of Katrina's storm surge life cycle generally do not exist because all tide gauges failed in the southeast Louisiana marsh and Mississippi during the brunt of the storm. The previous few days of water levels, as well the first few hours of the storm surge, were documented. Typically, one to two days before a storm such as Katrina makes landfall, the water increases 2-3 feet, known as the *surge forerunner*. On the day

of landfall, water starts to slowly increase, then rises faster as the hurricane eyewall makes landfall.

Despite the shortcomings of the gauges, they do provide a record of the wind and the surge before the eyewall comes onshore. They show unequivocally that tropical storm-force winds arrived several hours before the surge. A sample of Mississippi and Louisiana tide gauges are shown in Table 1, indicating that winds greater than 39 mph, and approaching hurricane strength, arrived between 4 and 8 hours before surge values of 8 feet occurred.

Table 1. Summary of wind and surge at three USGS Mississippi gauges (Ocean Springs, Mississippi Sound, and the mouth of the Pearl River). Two from Louisiana are also shown (Bay Gardene and Bayou La Loutre). Note that tropical storm-force winds occurred for several hours with surge insufficient to inundate most properties.

<i>Wind (mph)</i>	<i>Storm surge (feet)</i>	<i>Location</i>	<i>Time</i>
42	3.2	Ocean Springs	8/29 at 2:30AM
74	8.5	Ocean Springs	8/29 at 7:15AM
36	2.3	Mississippi Sound	8/29 at 12:00 AM
53	5.9	Mississippi Sound	8/29/ at 4:00AM
40	4.4	Bay Gardene	8/28 at 5:15 PM
58	6.9	Bay Gardene	8/29 at 12:00AM
35	1.3	Bayou La Loutre	8/28 at 9PM
56	3.3	Bayou La Loutre	8/29 at 5AM
55	3.0	Mouth of Pearl River	8/29 at 12:00 AM

The gauges are not designed to withstand the eyewall region at landfall, and do not present a complete picture of the surge cycle. Since observations are lacking, three methods exist to document the storm surge: computer model simulations, post-storm high-water measurements, and eyewitness accounts. A computer model approximates time-dependent hydrodynamic equations which represent water flow driven by wind and pressure fields. It can be used to explore the qualitative evolution of the storm surge, to fill in data gaps, and to explore physical relationships. High water mark surveys are conducted by government agencies (such as the National Weather Service, the Army Corps of Engineers, and the USGS), and private companies such as URS and Haag Engineering. Usually the elevations are recorded relative to vertical datum NAVD 88. They reflect either the stillwater elevation of the storm surge (areas outside the influence of breaking wave and wave runup, either far inland or inside buildings) or the stillwater elevation plus the wave runup component (areas in the wave swash zone - either breaking waves or wave runup). Stillwater elevation is recovered inside of commercial or residential structures as mud lines on walls or doors. The storm surge plus wave runup high water marks are generally found as debris or trash lines along coastal dunes, sloping terrain of the bay shoreline or the outside perimeter and exterior area of a structure. Based on the high water marks, 100 Waverly Drive experienced a 22.5-foot storm surge, with wave action of 1.0 feet or less superimposed on the surge.

To assess the timeline of the surge versus wind, the U.S. Army Corps of Engineers ADvanced CIRculation (ADCIRC) hydrodynamic model is used to simulate Katrina's storm surge. ADCIRC was initially developed under the Dredging Research Program, a 6-year program funded by the Army Corps of Engineers, Office of the Chief of Engineers. The model was developed as a family of 2- and 3-dimensional finite element based codes with the capability of simulating tidal circulation and storm surge propagation over very large computational domains, while simultaneously providing high-resolution output in areas of complex shoreline and bathymetry. In addition to numerous Army Corps of Engineer applications, ADCIRC has also been used by many universities, including LSU and Notre Dame, and companies such as WorldWinds, Inc., and the URS Corporation. The latter companies have performed work for Louisiana Natural Resources Department for research on the storm surge in Mississippi River Gulf Outlet, storm surge simulations for NASA, and other applications.

The ADCIRC simulation provides a timeline of the surge evolution. East of the hurricane's onshore winds, the surge can be seen moving up the Pearl River, Jordan River, and Bay St. Louis River at 5AM. Marsh regions near Pearlington and Pascagoula begin to experience inundation. Islands offshore, the Louisiana marsh, as well as Dauphin Island in Alabama, are partially underwater. The surge is below 5 feet in most regions. At 7AM and 9AM, this pattern continues, with surge values increasing along the Mississippi coast. Surge values in the Bay St. Louis area peak between 10AM and noon depending on the location, with most areas experiencing a peak surge between 20 and 25 feet. The depth and timing of the surge depends on the proximity to the coast and the land elevation. In addition, the impact on structures depends on their elevation.

Another ADCIRC simulation, based on the Interagency Performance Evaluation Task Force (IPET), was also consulted. IPET consisted of a distinguished group of government, academic, scientists and engineers who studied Katrina's storm surge. They show similar results with their simulations.

100 Waverly Drive is an apartment complex. The parking lot elevation varies from 5.2 to 5.8 feet. The ground around the apartments varies from 6.7 to 7.4 feet height. The first floor elevation of the buildings ranges from 10.65 to 10.85 feet. The second floor elevations range from 20 to 20.45 feet. An inspection of the apartments, as well as high water marks and FEMA post-storm surge maps, indicates a surge of 22.5 feet at this location. This report will discuss the timing of the surge with regard to both floors.

An analysis of ADCIRC simulations, video tapes, and eyewitness accounts indicates land inundation occurred about 9AM at 100 Waverly Drive. This is a little later than on the coastline, since this property is located inland north of HWY 90 and just east of HWY 603. The first floor of the apartments was inundated about 9:30AM. The second flood was inundated around 11AM.

Based on all available data, a time series of the sustained wind speed, wind gusts, and the surge is shown in Table 2.

Table 2. Summary of sustained winds, wind gusts, and inundation (relative to land elevation) from storm surge for August 29, 2005 at 100 Waverly Drive. Wave action less than 1.0 feet will be superimposed on the surge. Wind gusts of 100 mph likely began about 6:00AM. The first floor elevations of the apartments vary from 10.65 to 10.85 feet, and the second floor varies from 20 to 20.45 feet. The surge peaked at 22.5 feet at 11:30AM.

<i>Time (Aug. 29)</i>	<i>Sustained wind (mph)</i>	<i>Wind gusts (mph)</i>	<i>Level of inundation from storm surge relative to land (feet)</i>
1:00AM	40 (northeast)	50	land dry
4:00AM	54 (northeast)	65	land dry
5:30AM	58 (east-northeast)	80	land dry
6:30AM	71 (east-northeast)	110	land dry
7:00AM	83 (east-northeast)	120	land dry
8:30AM	99 (east-northeast)	130	land dry
9:30AM	110 (east-southeast)	140	11.0
10:00AM	99 (east-southeast)	135	14.0
10:30AM	93 (southeast)	110	18.0
11:30AM	79 (southeast)	95	22.5
12:00PM	72 (south)	85	20.5
1:00PM	60 (south-southwest)	75	17.0
4:00PM	48 (southwest)	55	8.0

### 3. Conclusions

The following conclusions can be stated about Hurricane Katrina's impact on 100 Waverly Drive on August 29, 2005:

- Tide gauges show tropical-storm force winds arrived several hours before significant flooding from surge.
- Computer models, National Weather Service radar, reconnaissance radar, dropsondes, surface observations, tide gauge data, eyewitness accounts, and video show hurricane-force winds, tropical storm-force winds, and strong wind gusts occurred 8 hours before the surge impacted Waverly Drive. Hurricane-force, then tropical storm-force winds continued for another few hours after inundation, but of less intensity. The Hurricane Research Division concurs with this assessment.
- Tropical storm-force sustained winds began at 1AM, and hurricane-force sustained winds started at 6:45AM. Peak sustained winds were conservatively 110 mph.
- Wind gusts were 20-80% higher than the official "sustained" winds. Wind gusts peaked between 130 and 140 mph according to the Hurricane Research Division and other sources. Wind gusts of 110 mph began around 5:45AM.
- 100 Waverly Drive is an apartment complex. The parking lot elevation varies from 5.2 to 5.8 feet. The ground around the apartments varies from 6.7 to 7.4 feet height. The first floor elevation of the buildings ranges from 10.65 to 10.85 feet. The second floor elevations range from 20 to 20.45 feet. The first floor of the apartments was inundated about 9:30AM. The second floor was inundated around 11AM. The surge peaked around 11:30AM at 22.5 feet. Waves were less than 1 foot during the storm at this location.
- This residence probably also experienced wind-driven rain damage through the roof, through window seals, and down the walls in some buildings. There was obvious roof damage as well as missing sections of roof in some locations. Debris had also penetrated the wall in one building.
- The possibility of a localized wind event exists. This event could be a microburst, a mesovortex, or a tornado (spawned by rotating thunderstorms, also called mesocyclones). Indeed, several mesocyclones were detected by the Slidell radar in the vicinity. Additionally, the radar algorithm cannot detect all mesocyclones in hurricanes, due to the low cloud base. More undetected mesocyclones are likely.

The Interagency Performance Evaluation Task Force (IPET), a distinguished group of government, academic, scientists and engineers who studied Katrina, has reached the same conclusions regarding the timing of the surge.

This report is based on current data, and subject to modifications from any new information. Relevant data are supplied in Powerpoint presentations attached to this report.

**AFFIDAVIT**

STATE OF \_\_\_\_\_Mississippi\_\_\_\_\_)  
COUNTY OF \_\_\_\_\_Oktibbeha\_\_\_\_\_)

I, Patrick J. Fitzpatrick, declare under penalty of perjury, that the foregoing report is true and correct.

Patrick J. Fitzpatrick  
Patrick J. Fitzpatrick

Subscribed and sworn to before me this 7<sup>th</sup> day of May, 2007.

Carol J. Martin  
Notary Public

My Commission Expires:  
NOTARY PUBLIC STATE OF MISSISSIPPI AT LARGE  
MY COMMISSION EXPIRES: Aug 7, 2010  
~~BONDED THRU NOTARY PUBLIC UNDERWRITERS~~

